SPATIAL ANALYSIS AND INTEGRATED PEST MANAGEMENT IN A LANDSCAPE ECOLOGICAL CONTEXT

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Abstract. Integrated pest management (IPM), forest management, and environmental management are levels of focus in an increasingly complex spatial and temporal hierarchy of land use. Evaluating and projecting the consequences of actions and activities taken at each of these levels involves use of spatial analytical methodologies. In this paper we (i) describe the concept and practice of IPM in a landscape ecological framework and (ii) consider the utility and limitations of geographic information systems for spatial analysis at the landscape scale of ecological integration. The architects of IPM used a holistic approach in their initial definition of the concept and the ecosystem was identified to be the appropriate level for abstraction. However, the ecosystem concept is inherently vague about scale and boundary. We suggest that the landscape ecological concept of *ecotope* (which embraces ecosystem functionality within the context of a land unit that has discrete boundaries) is the appropriate unit of abstraction. The ecotope concept permits consideration of land units (chorology) as well as land attributes (topology) in structuring analyses to evaluate and project the consequence of management actions. Although the procedures for landscape analysis are in an evolutionary state, all require use of spatially referenced data. For this reason, the geographic information system (GIS) has proven to be a useful tool. The GIS provides a "tool box" of functions that are helpful in landscape analysis and interpretation: map generalization/simplification, map overlay, spatial query/browsing, spatial statistics, spatial relationships, spatial reasoning.

INTRODUCTION

Integrated pest management (IPM) has been a dominant theme in forestry for more than two decades. The social, economic, and ecological impacts of insects and diseases are no less significant today than in the past. However, IPM has taken on a new significance, since forest management practices are now linked directly to larger environmental issues (e.g., deforestation, sustainable production, loss of biological diversity, global warming, cultural heritage). IPM, forest management, and environmental management are levels of focus in an increasingly complex spatial and temporal hierarchy of land use. Evaluating and projecting the consequences of actions and activities taken at each of these levels involves use of spatial analytical methodologies, which are only just beginning to be developed. Conclusions from the analyses are interpreted within the context of principles of ecology and management science. In this paper our specific objectives are (i) to describe the concept and practice of IPM in a landscape ecological framework and (ii) to consider the utility and limitations of geographic information systems for spatial analysis at the landscape scale of ecological integration.

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FOREST PEST MANAGEMENT IN A LANDSCAPE ECOLOGICAL CONTEXT

Integrated pest management

The formal beginning of IPM can be traced to the symposium proceedings *Concepts of Pest Management* (Rabb & Guthrie 1972). Since then, fundamental principles of IPM, and the forestry perspective on the subject (forest pest management - FPM), have evolved (Coulson 1981, USFS Anon. 1988). We are concerned here with both the concept and practice of IPM. Initially, IPM was a research and development activity. Emphasis was placed on issues of concept. Several specialized definitions were formulated. An example follows:

> ...the maintenance of destructive agents, including insects, at tolerable levels by the planned use of a variety of preventive, suppressive, or regulatory tactics and strategies that are biologically and economically efficient. It is implicit that the actions taken must be fully integrated into the total resource management process in both planning and operation. This means that pest management must be geared to the life span of the tree crop as a minimum and to a longer span where the resource planning horizon so requires...(Coulson & Witter 1984).

Implementation of this concept into forest management practice has proven to be a challenging task. Although the definition includes cryptic reference to a time frame, missing is any direct consideration of spatial scale or boundary. Pest management activities associated with suppression and prevention have quite different time and space constraints. The difficulty associated with merging concept and practice begins to be evident when we recognize that FPM is a site-specific activity, i.e., actions are directed to discrete land units of varying size. Furthermore, projecting the probable consequences of FPM practices involves interpretation based on ecological principles from several levels of integration, i.e., populations to landscapes. Simply stated, FPM practice embraces a hierarchy of land units and ecological levels of abstraction.

Landscape ecology and integrated pest management

Landscape ecology is the academic discipline that provides a scientific base for problem-solving and decision making in land-use management. Basic principles of landscape ecology are described in Forman & Godron (1986), Kolasa & Pickett (1991), Naveh & Lieberman (1984), Pickett & White (1985), Turner (1987), Turner & Gardner (1991), and Zonneveld & Forman (1990). This science deals with the study of landscape structure (components of the landscape and their linkages and configurations), function (quantities of flows of energy, materials, and species within and among landscape elements), and change (alteration in the structure and function of the ecological mosaic over time). Also included within the realm of landscape ecology are the actions and activities of humans relative to their environment.

From the onset, the developers of the IPM concept recognized the importance of a holistic approach and, therefore, identified the ecosystem (the biotic community together with the abiotic environment) as the appropriate level of focus (see Watt 1968 and Van Dyne 1969). The approach was appealing in that researchers could examine functionally how insect populations and communities influenced, or perhaps regulated, ecosystem level processes such as primary production, consumption, decomposition, or abiotic storage.

The fundamental problem with this approach is that the ecosystem concept is inherently vague about scale and boundary. In fact, ecosystems are often described simply as environments around special organisms of interest, e.g., the forest ecosystem, the cotton ecosystem, the apple orchard ecosystem. The term *ecotope* is used in landscape ecology to address ecosystem functionality within the context of a land unit that has discrete boundaries. Therefore, a landscape consists of a mosaic of ecotopes, i.e., tangible ecosystems (Figure 1).

With the ecotope serving as the basis for abstraction, landscapes can be viewed to have both horizontal and vertical dimensions. Horizontal (chorological) dimension refers to land units, which can be aggregated at different scales. For example, the convention used by the US Forest Service on national forests consists of a hierarchy beginning with the forest stand (the ecotope). Stands are combined to make compartments. Compartments are further clustered into a district. Districts form national forests (Figure 2). Vertical

(topological) dimension refers to land attributes, e. g., flora, fauna, soil, landform, etc. One function of landscape ecological research is to integrate information on land units and land attributes (Zonneveld 1990).

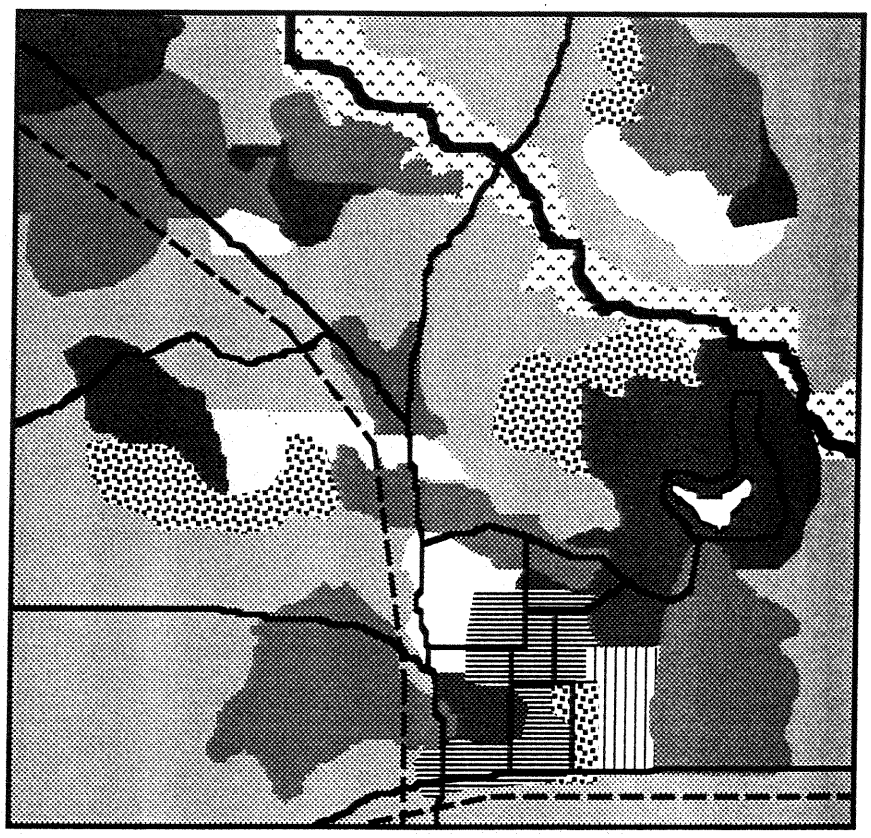

FIG. 1. forested landscape consisting of a mosaic of constituent ecotopes. The ecotope is the fundamental unit for IPM. One important function of landscape ecological research centers on integrating chorological (land unit) and topological (land attribute) information.

LANDSCAPE ANALYSIS, IPM, AND GIS

Geographic information systems and landscape ecology

One of the fundamental topics of study in landscape ecology centers on understanding how and why organisms are distributed across complex mosaics of ecotopes. Of course, this subject is of paramount importance to IPM as well. Changes in the distribution and abundance of a pest species can be assessed when studies of large-scale patterns and processes are interpreted within an ordered framework. The

hierarchy of land unit classification, with the ecotope serving as the base, is a useful way to organize landscape level analyses. Examination of the distribution and abundance of a pest insect species (or guild) requires analytical techniques that include the interaction of the horizontal and vertical dimensions of a landscape in the context of a specific landscape characteristic. For example we may be interested in how herbivory by bark beetles in mature pine forests (the landscape characteristic) is influenced by land unit configuration and specific land attributes such as tree species composition, other age classes of trees, soil type, hydrography, etc. Although the procedures for landscape analysis are in an evolutionary state, all require use of spatially referenced data. For this reason, the geographic information system (GIS) has proven to be a useful tool.

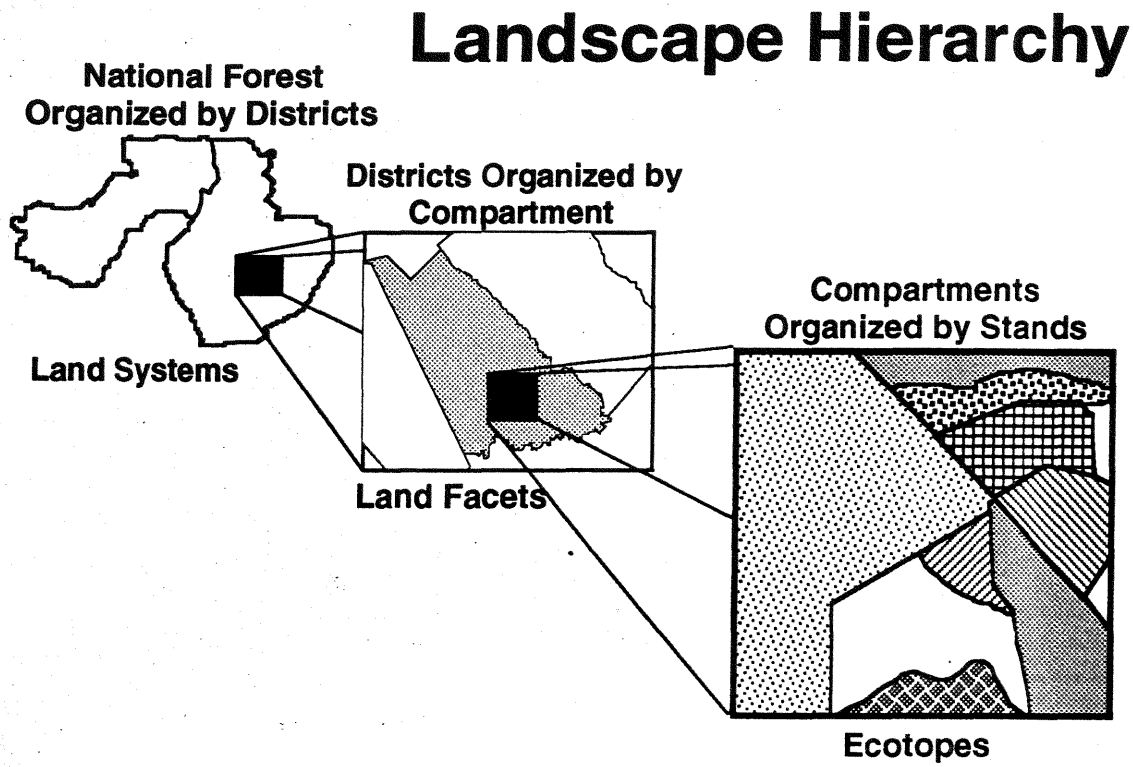

FIG. 2. With the ecotope serving as the basic level of abstraction, landscapes can be viewed at different scales. The convention used by the USDA Forest Service for national forests consists of a hierarchy beginning with the forest stand. Stands are combined to make compartments. Compartments are further clustered into a district. Districts form national forests.

Contemporary developments in GIS and the companion technologies of remote sensing and image processing are treated in Aronoff (1989), Buhyoff (1988 & 1990), Burrough (1988), Davis (1986), Laurini and Thompson (1992), Maguire, et al. (1991), Peuquet & Marble (1990), Star & Estes (1990), and Tomlin (1990). The appeal of GIS software is that it provides access to and display of geographically referenced databases. Interest in cartography provided the motivation for early GIS development. Potential practitioners looked beyond cartographic uses of GIS. Their expectation was that GIS could be used as a tool to address problems of spatial analysis and landscape modeling. However, the initial GISs had modest utility in this regard, with analytical functionality limited to Boolean operations, polygon overlay, buffer zones, and some statistical computation (Coppock 1989, Davis et al. 1988). This circumstance is beginning to change, as there is considerable research activity currently being directed to development of methods for spatial statistical analysis and landscape modeling (Turner & Gardner 1991).

Functionality of geographic information systems

GIS software and hardware usually consist of five subsystems (Burrough 1986). They are the: (1) data input subsystem, (2) data storage and management subsystem, (3) data visualization and output subsystem, (4) data manipulation and analysis subsystem, (5) user interface subsystem. Capabilities of the data manipulation and analysis subsystem determine how the GIS can be used to characterize landscapes.

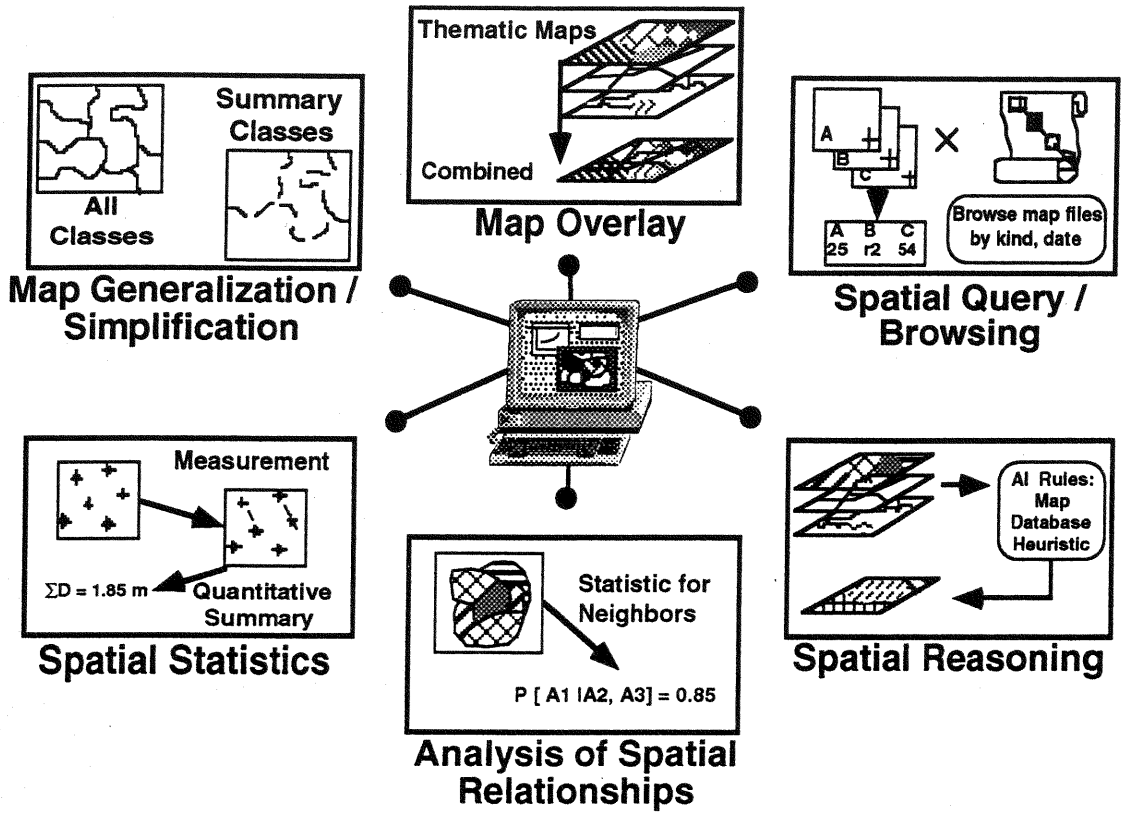

FIG. 3. The analytical functionality for most GISs includes utilities for map generalization/simplification, map overlay, spatial query/browsing, spatial statistics, analysis of spatial relationships, and spatial reasoning.

The data manipulation and analysis subsystem provides a "toolbox" of functions used to transform thematic map data. Manipulation and analysis either add value to the spatial database or solve spatial problems. The added value may come from creation of new thematic maps or visualizing spatial distributions. Spatial problems are solved using measurements of objects in space, by determining spatial relationships, and by creating predictive spatial models. Typical spatial analysis functions provided by GIS are (Burrough, 1986 and Laurini and Thompson, 1992) (Figure 3):

(1) *Map generalization and simplification*: These functions permit re-classification of spatial objects. The procedures allow the user to isolate the specific variables needed for analysis.

(2) *Map overlay*: Map overlay techniques can be used to combine thematic maps. These procedures allow for the synthesis of maps consisting of novel data themes.

(3) *Query and browse*: Query functions facilitate extraction of information from a spatial database. Browse functions permit exploring the contents of a spatial database.

(4) *Spatial statistics*: Usually, a GIS can provide descriptive statistics and histograms for attributes of spatial objects. Also, GIS usually provide for correlation analysis to compare spatial relationships that exist between and within thematic maps.

(5) *Analysis of spatial relationships*: A GIS can measure spatial arrangement of objects on a map. Spatial relationship measurements include proximity, distance, and trend.

(6) *Spatial reasoning*: Some systems provide tools for decision-making, incorporating both spatial information and heuristic knowledge. Human deductive reasoning can be imitated using expert systems techniques. The simplest systems use rule based reasoning to interpret within and among landscape data themes.

The GIS technology has improved dramatically in recent years. The suite of analytical tools has been broadened considerably. However, further development in statistics for spatial analysis and modeling is needed.

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